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GIS-based environmental and economic analysis of integrated crop-livestock production systems in southern Iowa

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$25,879 for year one
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Background

Crop and livestock production are important economic components for many rural communities. In 1992, Iowa led the nation in corn and hog production, and ranked second, third, seventh, and eighth, respectively in soybean, cattle and calves, poultry, and dairy cow production. Livestock and livestock products generated over 64% of the state's total cash farm receipts during 1992—more than $6.5 billion sales at the farm level.

Many Iowa hog farmers are adding sows to their herds, and production systems have become more confined and intensive. These changes have significantly altered the complementary relationship between crop and livestock production, in which the grain and roughage produced on cropland are used as feeds, and manure from the livestock provides valuable crop nutrients. Increasingly, many large confinement operations do not produce enough feed on their land and have to import from other farmers; they also lack insufficient land base to utilize the manure produced. Improper utilization of animal manure can lead to pollution of air, soil, and surface and groundwater.

While expansion of livestock production to complement Iowa crop production can enhance economic well-being, it must be coupled with the sustainable integration of animals with crops. Integration of crop and animal production will enhance long-term profitability by reducing costs of purchased inputs while properly utilizing manure.

However, information is needed on the size, scale, and location of livestock production systems as well as manure management strategies that are compatible with socio-economic objectives and environmental protection goals.

In southern Iowa, local cooperatives are developing financial packages to encourage farmers to go into large-scale animal production. The primary goal is to foster economic activity in this region, where out-migration of young people continues, the average age of the population is rising and increasingly dependent on transfer payments, soil and water resources are limited, and wages are slightly above minimum. While animal production systems in the region could be an economic boon, rapid expansion could increase the risks of environmental pollution. Degradation of water quality in the region could have adverse economic and public health impacts because water-based recreation contributes significantly to the regional economy and surface water is the major source of the drinking water supply.

This project was designed to provide information on the environmental impacts and socio-economic implications of livestock expansion in Iowa. A prototype decision support system that combines environmental and socio-economic modeling, assisted by a geographic information system (GIS) was used to determine livestock production systems that are in harmony with the natural environment. The specific objectives of the project were to

(1) delineate areas of a watershed suitable for livestock production facilities and land utilization of manure from an integrated crop-livestock production system,
(2) develop a socio-economic model for assessing the implications of various crop-livestock enterprises and technologies for local agribusiness and the regional economy,
(3) evaluate the effectiveness of animal manure and fertilizer management practices in reducing potential nutrient loading to

surface water at the watershed scale and assess nutrient balances in an integrated crop-livestock farming system, and

(4) evaluate economic incentives for stimulating the adoption of economically efficient and environmentally acceptable crop-livestock production practices.

Approach and methods

This study involved linking two physically based environmental models with a socio-economic model to examine the implications of livestock production expansion in Iowa. Both the environmental model and the socio-economic model were linked to a GIS database. Two very popular GIS software programs—ARC/INFO and ERDAS—were used extensively in the project to generate, spatially organize, and manipulate disparate data required by the models. The ARC/INFO GIS software analyzes, manages, and displays large volumes of landscape data, while ERDAS classifies land use information from Landsat imagery. The conceptual framework of the modeling system is illustrated in Fig. 1.

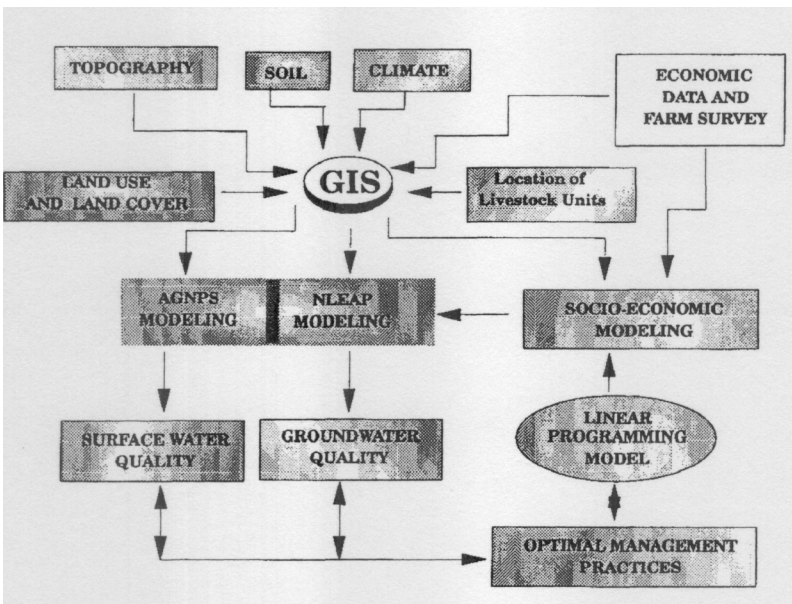

Fig. 1. Conceptual framework of modeling system and the GIS. The model determines: (a) the cropping systems (e.g., rotations) on each LMU (land management unit); (b) the livestock operations, if any, on each LMU; and (c) how much manure is applied to each LMU. The model also estimates the nutrient (nitrogen, phosphorus, potassium) requirements for the cropping systems and the total fertilizer value of the manure applied to each LMU. Typical outputs from the model included amounts of manure applied per acre, the cropping rotations, and the location of economically profitable livestock technologies. This information was then used as input to the environmental model.

The modeling system is tightly integrated in the sense that information on economically profitable livestock production systems is determined by the economic model and physical landscape attributes. The environmental modeling component provided both quantitative and qualitative information on the potential water quality impacts of livestock expansion at the watershed scale.

The investigators also surveyed residents in Adams and Clarke Counties about their attitudes toward the expansion of livestock operations in their area.

Environmental modeling: Two biophysical models of water quality, AGricultural NonPoint Source (AGNPS) and Nitrogen Leaching and Economic Analysis Package (NLEAP), were also used in the project. Both models are widely used to determine the impact of agricultural management strategies on surface and groundwater quality. The AGNPS model simulates the impact of alternative agricultural management systems on surface water quality. It considers hydrology, sediment transport, and chemical movement in watersheds. Point source inputs of sediment and nutrients (e.g., from feedlots and animal production systems) are also considered. The AGNPS model estimates several water-quality-related parameters, including total water-soluble and sediment-bound nitrogen and phosphorus, total runoff volume, peak discharge rate, soil erosion rate, sediment yield, and chemical oxygen demand.

The NLEAP model was developed to provide a rapid and cost-effective approach for assessing nitrate-nitrogen leaching and groundwater pollution potential of agricultural production areas. The modeling system was designed for farmers, resource managers, and extension personnel who require rapid assessment of vulnerability of aquifers to nitrate pollution. The NLEAP model uses mechanistic relationships to estimate nitrate leaching potential and aquifer risk indices, nitrogen use efficiencies, and nitrogen budget, and then recommends alternative management practices to reduce

potential pollution problems. In applying the model, users provide site-specific information on soils, climate, land use, nutrient management, and economics. The NLEAP model then translates these data into projected nitrate leaching, potential off-site impact on the aquifer, and economic impact of the alternative strategy.

Socioeconomic modeling: The economic modeling component of the project was conducted at three spatial scales: farm, enterprise, and watershed. The farm and enterprise scale economic modeling involved estimating costs and returns from several livestock expansion strategies. Economic analysis at the watershed scale addressed choice, scale, and location of the technologies that are consistent with a given objective function as well as a set of environmental quality constraints. In the watershed economic modeling,

- livestock and crop production technologies were specified at the land management unit (LMU) or tract level,
- feasible technologies for a given LMU or tract were determined by using a site-selection decision system,
- the structure of the watershed model was dynamically altered in response to changes in the site-selection criteria,
- a simple transportation algorithm was embedded to reflect costs of hauling and disposal of the manure,
- and data on land use and economically profitable livestock production systems from the socioeconomic model were transferred to the environmental models.

Manure transportation within and outside the study domain (e.g., watershed, county) is a critical part of the model because almost all of the feasible livestock production sites that meet the selection criteria are located on the perimeter of the watershed.

Analysis of the community impacts of alternative livestock expansion strategy was based on an application of an input/output (I/O) model for Adams and Clarke Counties. The generalized I/O accounting of a region's economy tracks input purchases from other sectors and output sales to other sectors, including final demand categories. It also adjusts these transactions for purchase from in-state versus out-of-state sources and sums the successive rounds of transactions to arrive at an estimate of total impact of a livestock expansion strategy. Transactions were traced on the basis of output activity by each sector, including measures such as income, value-added, and employment effects.

System application to Lake Icaria watershed: The 7,075-ha (17,280-acre) Lake Icaria watershed, located in Adams County about 8 km (5 miles) from Corning, Iowa, and approximately 112 km (70 miles) southwest of Des Moines, was considered in this project. Drainage from the watershed empties into Lake Icaria, which is the major source of rural drinking water for the region. Lake Icaria has a surface area of about 280 ha (700 acres) and is part of the 760 ha (1900 acres) Lake Icaria Recreational Area, which provides facilities for boating, fishing, swimming, camping, and other recreational activities. Lake Icaria also provides water for domestic and industrial use within Corning and surrounding towns. A creamery, the second largest in Iowa, is located at Corning and produces about 4 million kilograms of butter annually. Much of the water for food processing at this industry is obtained from Lake Icaria.

Agricultural land use and land cover in the Lake Icaria watershed consist primarily of row crops integrated with livestock (hog, beef cattle, poultry, sheep) production enterprises. Cropped areas compose about 49% of the watershed, while 4.6% of the watershed area is identified as idle land. Pasture covers 22.4% of the watershed area, while 11.6% of the watershed is placed under the Conservation Reserve Program. The remaining 12.5% of the Lake Icaria watershed consists of water bodies, farmsteads, roads, and parkland.

Livestock, primarily hogs and cow-calf herds, is an important enterprise for farmers in the watershed. A recent field survey identified 580 cattle and several medium-scale hog confinement operations in the watershed. The cattle herds are divided between 14 pasture operations distributed throughout the water-

shed. The hog confinement operations are located adjacent to parkland on the north side of the watershed. In general, past evaluations by state conservation personnel of the livestock operations in the Lake Icaria watershed have indicated some overgrazing, with about 50 ha (125 acres) of pasture land showing soil erosion problems. A recent preliminary soil erosion study of the watershed also indicates that about 2,600 ha (6,500 acres) of cropland have soil erosion rates that exceed established tolerable limits. Almost all of the soil eroding from the watershed ends up as siltation within the lake, causing an annual loss in storage capacity of 17,500 cubic meters.

Social/behavioral assessment: The acceptability of various livestock expansion strategies and associated environmental mitigation options was evaluated by an approach known as contingent valuation, which is widely considered the best tool of its kind for this purpose. Inclusion of costs and benefits of changes in the availability of commodities not normally traded in the marketplace, such as clean water and the community quality of life, were an important part of this cost-benefit analysis.

In the project, the assortment of livestock expansion scenarios posed to farmers and nonfarmers involved livestock expansions outside their direct control. These scenarios were defined by using the economic model as well as the GIS modeling procedures used in delineating sustainable production systems before they were submitted to the survey audience.

The objectives of the contingent valuation technique survey were to examine rural residents' perceptions of expansion of livestock production (particularly hogs) in their neighborhood and their willingness to pay for drinking water contamination originating from excess manure produced. The survey first addressed respondents' circumstances and attitudes toward water quality protection. Several questions were then asked to help explain respondents' concerns about the proximity of a new 1,000-sow confinement operation.

The second section began by presenting information on the goals and the potential costs of a water quality protection program. The survey was specifically designed to test respondents' reactions to a series of hypothetical situations involving alternative programs that influence water quality in their region and local economy. The payment vehicle was an additional $300 per year levy on their water bill or a $300 annual increase in local taxes to fund a water quality protection program. The valuation question asked an individual whether he or she would vote "Yes" or "No" to support the program, given the specific amount of income reduction (e.g., taxes) needed to support the program. Respondents were also asked to provide reasons for their response. The survey also collected data on age, gender, education, employment status, and household.

Surveys were mailed to 1,000 randomly selected residents of Adams and Clarke Counties. A total of 447 surveys were returned, of which 444 were usable. Over 44% of the respondents were 60 years of age or older; the median income for all respondents was slightly above $20,000 per year. The annual income for about 50% of the respondents was in the range $20,000 to $49,999.

Livestock expansion strategies: The livestock expansion strategies utilized in the research were designed with the objective of determining how outputs from the various models vary with changes in each production strategy. Table 1 summarizes the livestock expansion strategies. Associated with each expansion strategy is a set of landscape characteristics and economic and socially acceptable supporting practices (e.g., animal manure/nutrient management) that reduce adverse environmental impacts. For each production strategy, outcomes measured include: (a) optimal production and land application sites, (b) potential impacts on groundwater quality, (c) economics of proposed expansion—relative to current practices—and of transporting excess manure, (d) tradeoff between scale and extent of expansion within the watershed, and (e) acceptability of the production strategy.

Findings

The decision-support system for selecting livestock production sites was used to analyze the

Table 1. Livestock production and expansion strategies

	Livestock Production Technology	Small	Medium	Large
I	Hog (Confinement)	100 sows 0.8 ha 549,600 gallons	250 sows 1.2 ha 1,405,500 gallons	1,000 sows 4 ha 5,622,000 gallons
II	Hog (Deep Bedded]	100 sows l h a 896 tons	250 sows 1.2 ha 2,238 tons	500 sows 2 ha 5,105 tons 968,700 gallons
III	Hog (Pasture)	50 sows 0.8 ha 3.6 ha of pasture 213 tons	100 sows 1.2 ha 7.1 ha of pasture 427 tons	250 sows 1.6 ha 19 ha of pasture 1,066 tons
IV	Beef (Rotational Grazing)	40 cows 0.8 ha 25.9 ha of pasture 60 tons	100 cows 1.2 ha 64.8 ha of pasture 150 tons	250 cows 1.6 ha 161.9 ha of pasture 375 tons
V	Beef (Conventional Grazing)	40 cows 0.8 ha 40.5 ha of pasture 60 tons	100 cows 1.2 ha 101.2 ha of pasture 150 tons	250 cows 1.6 ha 253 ha of pasture 375 tons

Note: 1 ha = 2.47 acres

suitability of the watershed landscape for the various livestock production strategies. Figures 2 and 3 summarize the optimal sites for locating the indicated production system given environmental, social, and economic constraints. In general, for the 7075-ha (17,480 acres) Lake Icaria watershed, about 10,57,14 and 22 ha were suitable for siting large deep-bedded hog, large hog confinement, large hog pasture, and large beef rotational grazing production systems, respectively. The variables considered included slope, aspect, depth to water table, depth to bedrock, soil permeability, proximity to roads, distance to streams, and size of production system. The use of the decision support system provided a technically sound approach for incorporating the numerous physical, economic, and social constraints in the livestock production enterprise.

Manual delineation of suitable land areas for manure application requires a skilled map reader and experienced hydrologist, making it suitable for dealing with small areas. However, because of current and emerging regulations, area-wide assessment via computer techniques is needed to insure environmental protection. The use of large spatial databases for land application site suitability assessment may be less labor intensive and cost-effective. Figure 4 shows the suitable land areas for manure application in the Lake Icaria watershed.

Survey results: Survey results indicated high concern over the potential contamination of local drinking water supplies from large confinement operations. Survey respondents were asked to indicate their level of concern about the location of a new 1,000-sow confinement unit within varying distances from their homes. Over 80% of the respondents were somewhat or seriously concerned about the potential for nitrate contamination of their drinking water supplies. The level of concern about potential nitrate contamination was related to the respondent's occupation, gender, age, and the source of drinking water. Income and educational differences were significant in only one instance. Respondents indicated that even at distances of 8 kilometers (5 miles), they were very concerned about the risk to drinking water.

Over 50% of the respondents indicated that environmental concerns are top or high priority as a national and local policy issue. Rankings of environmental issues varied on the basis of occupation, gender, and educational levels of the respondents. County of residence, source of water supply, age, income, and the presence of children in the home were influential neither in the relative priority of environmental to other concerns nor in the ranking of environmental issues relative to each other.

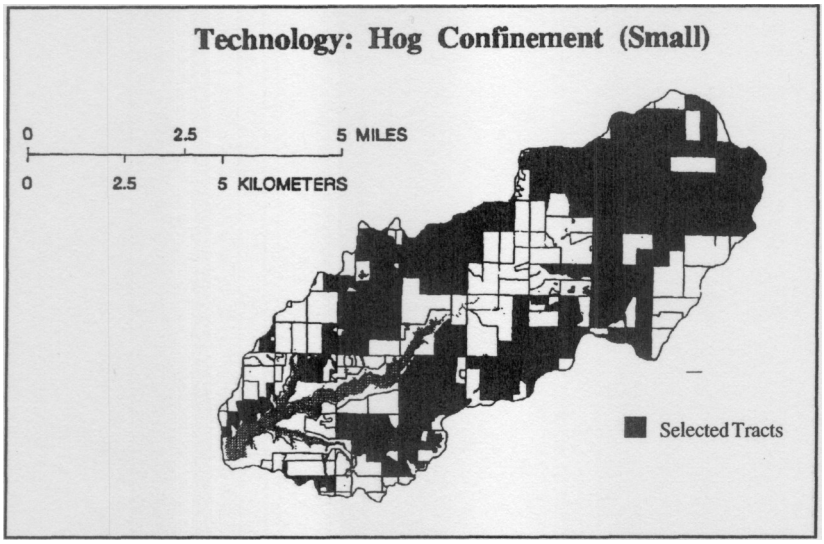

Fig. 2. Suitable sites for small hog-confinement facilities within the Lake Icaria watershed.

People engaged in farming were more concerned about a large confinement operation located near their residence than those employed in town or retired. However, respondents engaged in farming were much more likely to consider environmental concerns at the local and national level as low priority. Older respondents were more seriously concerned about the environmental impact of large confinement operations than younger respondents. In a state with a high proportion of elderly citizens, such as Iowa, this age factor may result in higher levels of concern for water quality from siting of livestock facilities.

The selection of suitable sites for locating any facility is a complex process. The decision-maker must be able to manipulate large amounts of geographic data and address multiple planning objectives in an efficient and systematic manner. Traditional site selection techniques have proved inefficient because of the large amounts of data required and the multi-criteria nature of the process. Therefore, the use of spatial decision support systems for livestock production planning and site selection is a cost-effective alternative allowing incorporation of many variables as well as efficient handling of large.amounts of data. These computer-based systems help to delineate alternative siting strategies that are consistent with specified planning objectives. Compared to traditional site selection techniques, the spatial decision support system enables disproportionate allocation of weights, which gives the decision-maker added flexibility to assess the relative importance of a criterion. It also provides an interactive framework and user-friendly spatial modeling environment that the planner or decision-maker can use to incorporate physical, economic, and environmental constraints into the site selection process and to compare the attractiveness of several competing alternative sites.

Although the spatial decision support system developed in this project advances decision analysis for planning sustainable livestock production systems, the system needs refinement. First, application of the spatial decision support system to more complex decision-making is required to further verify its feasibility and capability. Second, integration of other multicriteria decision-making techniques into the existing system is needed to increase the applicability of the system and extend the usefulness of GIS for spatial decision-making. Finally, incorporation of "expert" systems and process models into the existing system would extend its usefulness.

Implications

To address the environmental pollution problems associated with crop and livestock production, state and federal agencies have formulated regulatory policies. In addition, an increasing number of citizen suits are being filed for environmental pollution caused by human activities. In the livestock production sector, odor nuisance suits have surfaced during the past several years, with the majority involving swine production. In some states, citizens are organizing to demand increased environmental enforcement against livestock producers. As public concerns grow, additional regulations are enacted and suits are filed, there is tremendous pressure on farmers to ensure that all forms of pollution are controlled or in some cases even eliminated. Farmers and resource managers need tools to manage production systems in a sustainable manner. Adverse environmental impacts of live-

stock production can be minimized only if producers are provided with reliable management decision support tools in conjunction with accurate information on the implications of production expansion strategies.

Growing awareness of the linkages between environmental quality (air, soil, and surface and groundwater) and agriculture has focused attention on modifying production systems to enhance sustainability. Sustainable agriculture has three inter-related components: economics, environment, and society. Quite often, these components have been studied independently, without consideration of their potential linkages. This research used a holistic approach to address the conflicting constraints in integrated crop-livestock production systems, with attention given to expansion in Iowa livestock

Some additional research issues need attention. For example, the original project objectives did not address the odor issue, which is an important consideration in the planning of livestock production systems. Many of the water quality issues associated with the siting of livestock facilities also pertain to nuisance odors. The decision support system has since been extended to address issues odor issues in livestock production. A spatial analysis framework, similar to the site selection system, was developed to assess the extent of an odor plume given the characteristics of a livestock production enterprise.

Overall, community involvement in discussing alternative manure management strategies and odor management technologies may increase awareness and alleviate some the recent concerns associated with expansion of livestock production. Survey results suggest that widespread concerns remain.

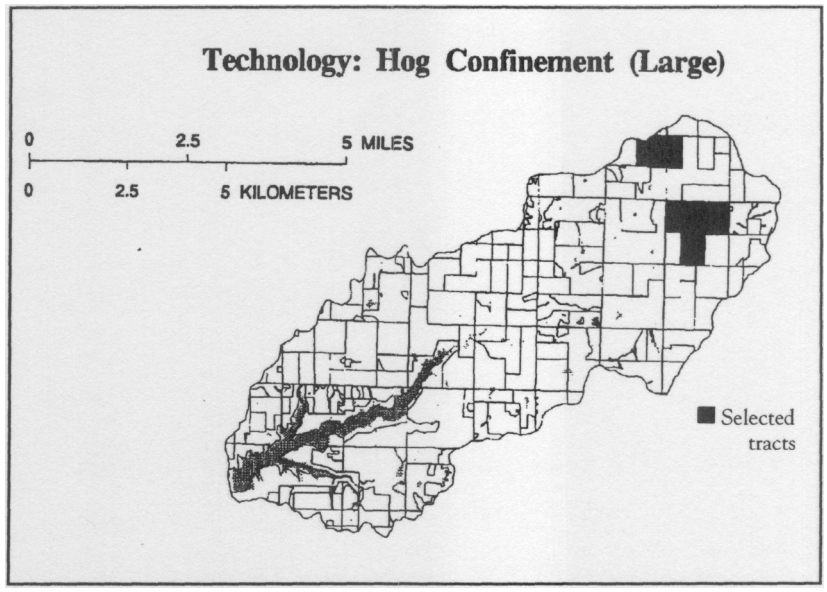

Fig. 3. Suitable sites for large hog-confinement facilities within the Lake Icaria watershed.

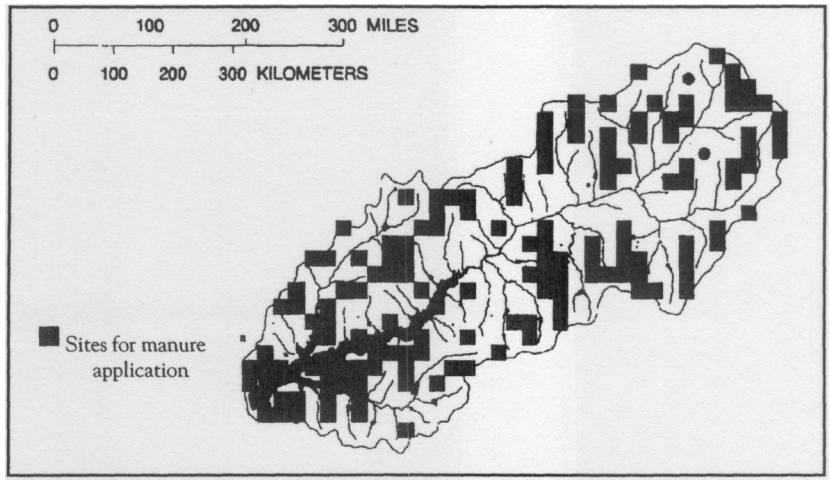

Fig. 4. Land areas of the Lake Icaria watershed suitable for manure application.

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